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Rotation in the ZAMS: Be and Bn stars

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Abstract. We show that Be stars belong to a high velocity tail of a single B-type star rotational velocity distribution in the MS. This implies that: 1) the number fraction N(Be)/N(Be+B) is independent of the mass; 2) Bn stars having ZAMS rotational velocities higher than a given limit might become Be stars.

1. ZAMS rotational velocities of Be stars

The observed $V\sin i$ of 127 galactic Be stars were corrected for uncertainties due to the gravitational darkening effect with the FASTROT models (Frémat et al. 2005). Using the same models we calculated the today true rotational velocity V of each star by determining its inclination angle i. With evolutionary tracks for rotating stars we determined the mass and age of the studied stars (Zorec et al. 2005). From each V we estimated the corresponding $V_{\rm ZAMS}$ by taking into account four first order effects affecting the evolution of equatorial velocities: 1) variation induced by the time-dependent stellar radius; 2) angular momentum (AM) loss due to mass-loss phenomena in stars with mass $M \gtrsim 15M_{\odot}$ and conservation of AM for $M \lesssim 15M_{\odot}$; 3) changes of the inertial momentum due to evolutionary effects and to the rotation using 2D barotropic models of stellar structure (Zorec et al. 1988); 4) internal redistribution of the AM in terms of the meridional circulation time scale parameterized from Meynet & Maeder's (2000) models. The obtained $V_{\rm ZAMS}$ against the stellar mass are shown in Fig. 2a, where there is a neat mass-dependent limiting cut $V_{\rm min}(M)$ that confines all studied Be stars in a high velocity sector. This indicates that stars need to have $V_{\rm ZAMS} \gtrsim V_{\rm min}$ to become Be in the MS phase. For each mass-interval we divided the $V_{\rm ZAMS}$ by $V_{\rm min}$ and obtained the global histogram shown in Fig. 2b. The fit that better describes the distribution of $V_{\rm ZAMS}(M)/V_{\rm min}(M)$ obtained is a Gaussian tail. The histogram concerns only 17% roughly of stars out of the whole B star MS population. Since more than 80% of MS B-type stars must then be in the $V_{\rm ZAMS}/V_{\rm min} \lesssim 1$ interval, it implies that Be stars do not form a separate distribution, but possibly a tail of a general distribution that encompasses the whole B-star MS population.

2. Mass-independent frequency of Be stars

The number of detected Be stars is given by: $\mathrm{d}N(Be,i) \propto P_{\rm Be}E_{H\alpha}(T_{\rm eff},\tau,i)\phi(\tau)$ $\times N(T_{\rm eff})\sin i\mathrm{d}\tau\mathrm{d}i$, where $P_{\rm Be}$ is the mass-independent probability of becoming

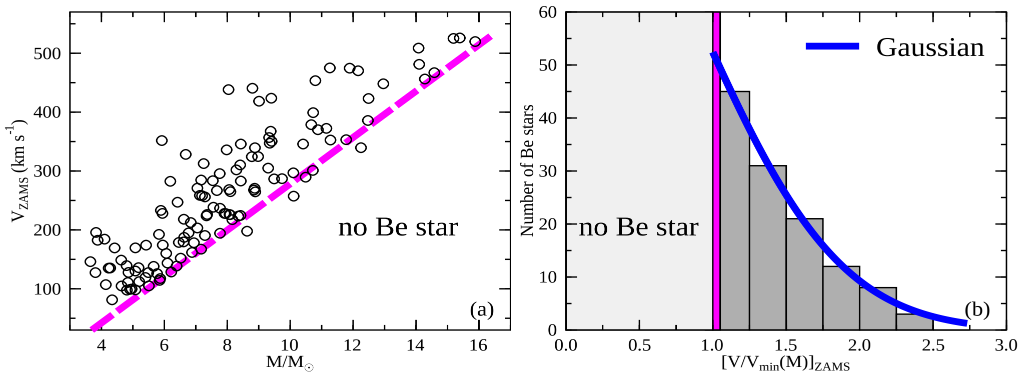


Figure 1. a) Distribution of the equatorial velocities in the ZAMS of the studied Be stars against the mass . b) Frequency distribution of $V_{\rm ZAMS}/V_{\rm min}$ and fit with a Gaussian function. No Be star has $V_{\rm AMS}/V_{\rm min} < 1$

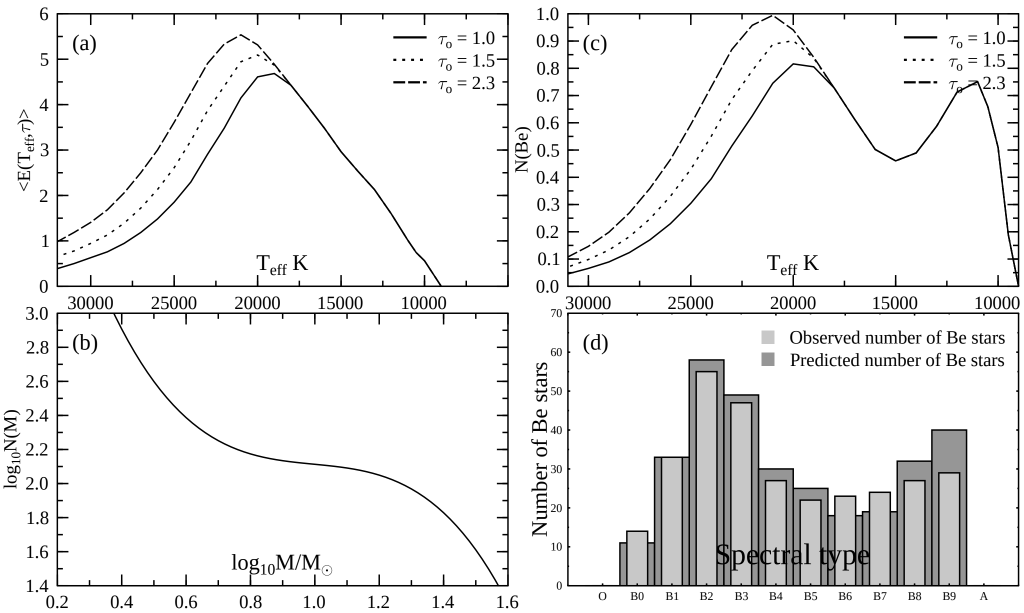
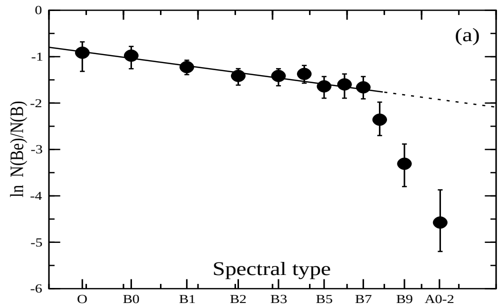


Figure 2. a) Hα emission intensity function as a function of $T_{\rm eff}$ and τ_o. b) Number of stars around the Sun in an apparent V=7 magnitude limited volume. c) Normalized predicted number of Be stars near the Sun. d) Comparison of predicted with observed number of Be stars near the Sun

Be star (see Sect. 1.); $E_{H\alpha}$ is the probability of detecting a Be star measured in terms of the intensity of the Hα emission produced by a disc with opacity τ shown in Fig. 1a; $N(T_{\rm eff})$ is the total number of stars with a given $T_{\rm eff}$ given by the IMF function; $\sin i$ is the probability of seeing the disc at inclination i. We can integrate the indicated relation for an apparent V=7 magnitude limited volume to represent the fraction of Be stars near the Sun. The reduced apparent magnitude IMF function is shown in Fig. 1b. It comes then that the product of $E_{H\alpha}$ with the 'local' IMF produces the curves shown in Fig. 1c, which represent



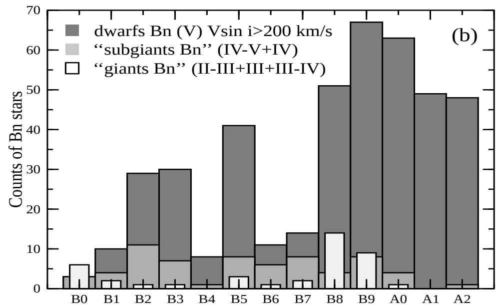


Figure 3. a) Apparent magnitude limited counts (V=7mag) of dwarf Be stars relative to dwarf B stars. b) Apparent magnitude limited counts (V=7mag) of Bn stars. Most Bn stars are dwarfs, which may indicate that they are fast rotators in the first MS evolutionary phases

the normalized predicted number $N(Be)$ of Be stars. The comparison of the predicted ($\tau_o\!=\!1$) with the actually observed number of Be stars around the Sun is shown in Fig. 1d. This shows that the apparently bi-modal distribution of Be stars around the Sun against the spectral type is entirely explained by the interplay of the probability of detecting Be stars ($E_{H\alpha}$), the shape of the IMF and $P_{\rm Be}(M)$ = constant.

3. Some Bn stars might be progenitors of Be stars

Figure 3a shows the apparent V=7 magnitude limited counts of dwarf Be stars relative to dwarf B stars. There is an apparent lack of dwarf Be stars cooler than spectral type B7. This could be due to genuine Be stars whose discs are minute and/or too cool for the Hα emission be detectable and/or, to fast rotating B stars that still had not attained the required properties to become fully-fledged Be stars. According to findings in Sect. 1., which are supported by those in Sect. 2., the relation shown in Fig. 3a should be straightened, so that $\ln N(Be)/\ln N(B)$ = constant. It has been shown in Zorec et al. (2005) that there is a lack of Be stars with masses $M \lesssim 7M_\odot$ in the first half of the MS phase. However, Fig. 3b shows that apparent V=7 magnitude limited counts of Bn stars increase strongly at spectral types cooler than B7. Since most of them are dwarfs, they probably had not enough time to attain the angular velocity ratio $\Omega/\Omega_c \simeq 0.9$ that characterizes Be stars (Frémat et al. 2005). The determination of the $V_{\rm ZAMS}$ of 100 Bn stars is underway. This will enable us to see which of them has the required condition $V_{\rm ZAMS} \gtrsim V_{\rm lim}$ to become Be. Other related subjects can be found in http://www2.iap.fr/users/zorec/.

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